

THE TEMPERATURE OF NITROGEN ON PLUTO; K.A. Tryka, Division of Geological and Planetary Sciences, Caltech, R.H. Brown, Jet Propulsion Laboratory, D.P. Cruikshank, NASA Ames, T.C. Owen, Institute for Astronomy, University of Hawaii

Millimeter flux measurements of the Pluto/Charon system [1,2] have placed the temperature of Pluto between 30 and 44 K. This is in conflict with previous infrared flux measurements obtained by IRAS [3,4] which placed the temperature of Pluto closer to 55 K. Recent spectroscopic measurements of Pluto have shown that nitrogen and carbon monoxide exist on the surface of Pluto [5], in addition to the methane previously identified [6]. Laboratory work [7,8] has shown that the  $2.148 \mu\text{m}$  band of solid  $\text{N}_2$  is temperature dependent. Using laboratory data of  $\text{N}_2$  and groundbased spectral data of Triton [9] Tryka et al. [7] determined a temperature for the nitrogen on Triton which is in agreement with Voyager 2 measurements. Thus, an analysis of the spectrum of Pluto is expected to yield an accurate temperature for the nitrogen on that body.

Solid nitrogen exists in three phases [10]. The cubic  $\alpha$  phase exists at temperatures below 35.6 K at 0 pressure; the hexagonal  $\beta$  phase exists at temperatures above 35.6 K and below the triple point (63.15 K) at 0 pressure. The  $\gamma$  phase exists only at high pressures and is not relevant to planetary surfaces.

There is a dramatic change in the shape of the  $2.148 \mu\text{m}$  band in solid nitrogen as it passes from the  $\beta$  to  $\alpha$  phase [11]. In the  $\beta$  phase the band is quite shallow and very broad while in the  $\alpha$  phase the band is much deeper and very sharp. More recent work has shown that changes in the spectral band are not only a function of the nitrogen phase, but also a function of temperature [7,8]. As  $\beta \text{ N}_2$  is cooled the  $2.148 \mu\text{m}$  band systematically deepens and gets narrower (Figure 1). In addition, between 35.6 K and about 41 K a second feature appears at  $2.16 \mu\text{m}$ . Thus the shape of the spectral band is a reliable indication of the temperature of the nitrogen.

With Hapke scattering theory [12] and absorption coefficients derived from our laboratory measurements of  $\text{N}_2$  ice we have modeled the spectrum of Triton [9]. By comparing a Hapke scattering model to the measured spectrum from Triton we determined the temperature of the  $\text{N}_2$  on the satellite's surface to be  $38 (+2, -1)$  K which is in accord with the measurements of Voyager 2 [13,14].

Applying this technique to Pluto we find that the temperature of  $\text{N}_2$  on that body is  $40 \pm 2$  K (Figure 2). If the distribution of  $\text{N}_2$  on the surface and in the atmosphere of Pluto is controlled by vapor pressure equilibrium (as is apparently the case on Triton) the areas of  $\text{N}_2$  will be isothermal while areas bare of  $\text{N}_2$  could have a significantly higher temperature. By considering Pluto to be a non-isothermal body we were able to create a model which is able to match the millimeter and infrared flux points simultaneously.

Our model Pluto consists of a spherical planet with symmetric, isothermal  $\text{N}_2$  polar caps. The equatorial region is bare of  $\text{N}_2$  and assigned a bolometric albedo. Its temperature is determined by instantaneous equilibrium [15]. Charon is modeled as a spherical planet with an albedo typical of icy satellites and its temperature is also calculated using instantaneous equilibrium.

Figure 3 shows a sample flux model

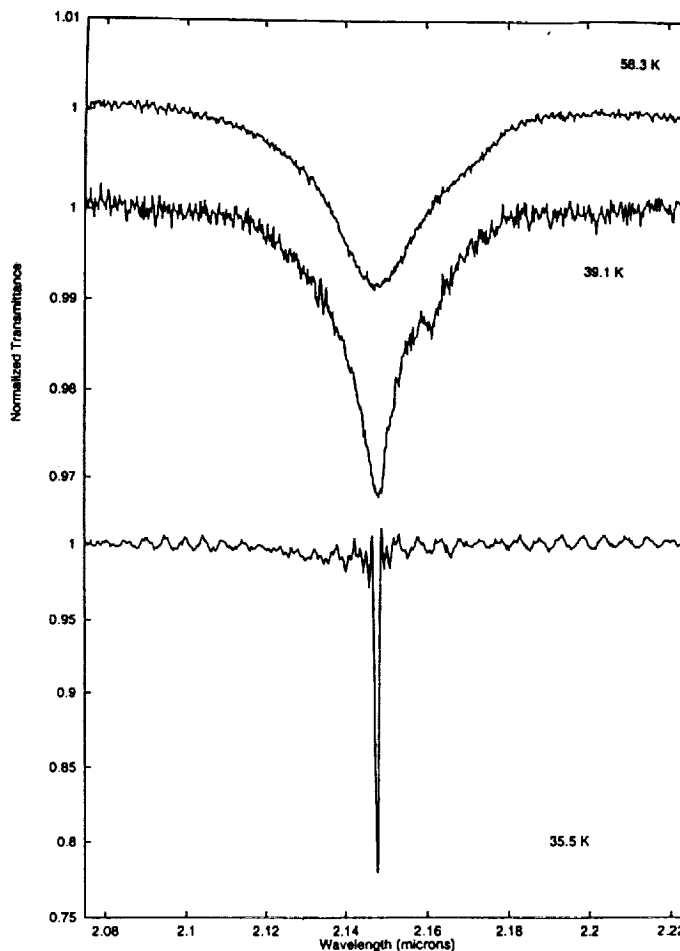


Figure 1

## THE TEMPERATURE OF NITROGEN ON PLUTO: Tryka, K.A. et al.

(solid line) along with flux measurements of the Pluto/Charon system (shown with error bars) and upper limits to fluxes determined by non-detections (short horizontal lines). The model has polar caps down to  $\pm 20^\circ$  latitude, an equatorial albedo of 0.2, and a Charon albedo of 0.4. This model falls within the error bars of all the data points with the exception of the  $1200\text{ }\mu\text{m}$  measurement. Models with other parameters also fit the data, but they have these points in common; the polar caps are very large (extending to latitudes of  $\pm 20^\circ$ – $\pm 25^\circ$ ) and the equatorial albedo of Pluto is quite dark ( $< 0.4$ ). Thus, it is possible to match the observed flux points with a simple model of Pluto.

## References

- [1] S.A. Stern, D.A. Weintraub, and M.C. Festou, *Science*, **261**, 1713-1716 (1993).
- [2] W.J. Altenhoff et al., *Astron. and Astrophys.*, **190**, 15-17 (letter) (1988).
- [3] M.V. Sykes, R.M. Cutri, L.A. Lebofsky, and R.P. Binzel, *Science*, **237**, 1336-1340 (1987).
- [4] H.H. Aumann and R.G. Walker, *Astron. J.*, **94**, 1088-1091 (1987).
- [5] T.C. Owen et al., *Science*, **261**, 745-748 (1993).
- [6] D.P. Cruikshank, C.B. Pilcher, and D. Morrison, *Science*, **194**, 835-836 (1976).
- [7] K.A. Tryka, R.H. Brown, V. Anicich, D.P. Cruikshank, and T.C. Owen, *Science*, **261**, 751-754 (1993).
- [8] W.M. Grundy, B. Schmitt, and E. Quirico, *Icarus*, **105**, 254-258 (1993).
- [9] D.P. Cruikshank et al., *Science*, **261**, 742-745 (1993).
- [10] T.A. Scott, *Phys. Rep.*, **27**, 89-157 (1976).
- [11] J.R. Green, R.H. Brown, D.P. Cruikshank, and V. Anicich, *Bull. Am. Astron. Soc.*, **23**, 1208 (1991).
- [12] B. Hapke, *JGR*, **86**, 3039-3054 (1981).
- [13] A.L. Broadfoot et al., *Science*, **246**, 1459-1466 (1989).
- [14] B. Conrath et al., *Science*, **246**, 1454-1459 (1989).
- [15] R.H. Brown, D. Morrison, C.M. Tedesco, and W.E. Brunk, *Icarus*, **52**, 188-195 (1982).

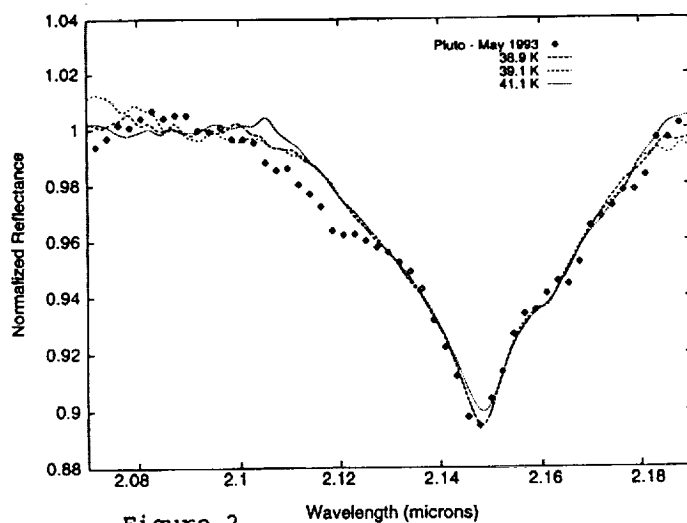


Figure 2

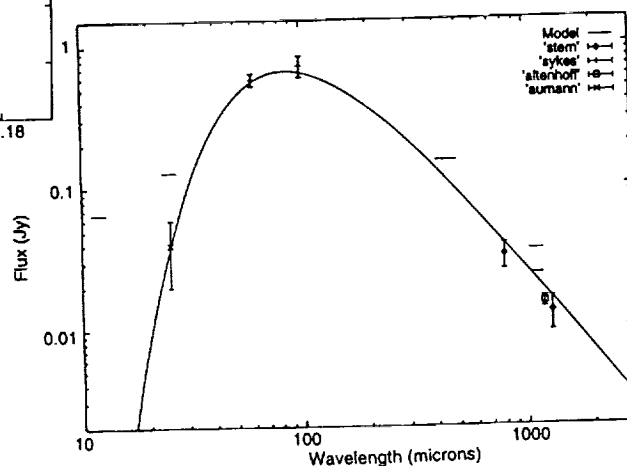


Figure 3